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MAGO: An Innovative Approach to Magnetic Target Fusion

Researchers from three Los Alamos Divisions in an historic collaboration with researchers from the premier Russian nuclear weapons laboratory VNIIEF are studying the characteristics of a plasma-formation scheme for magnetized target fusion.

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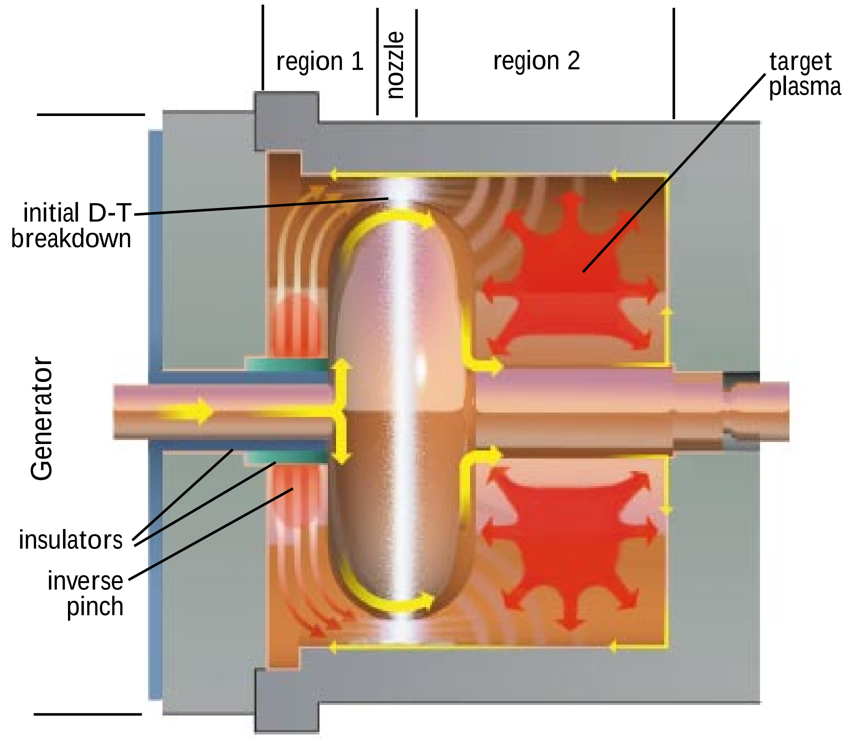

Fig. 1. The cylindrical copper MAGO chamber filled with a static gas mixture of deuterium and tritium.

Fusion, the process that produces thermonuclear reactions in the sun, may someday solve many of the world's energy problems as a virtually inexhaustible, relatively clean, and cost-effective alternative energy source to the diminishing oil and gas reserves. Achieving sustained thermonuclear fusion under laboratory conditions, however, is scientifically challenging. For several decades, researchers worldwide have been investigating methods of controlling thermonuclear reactions primarily via two independent concepts: inertial confinement fusion (ICF) and magnetic fusion. Both concepts involve the creation of a hot, dense plasma heated to millions of degrees and held together long enough to produce useful energy through fusion reactions.

ICF experiments involve the implosion of a pearl-size capsule that contains fusion fuel in the form of hydrogen isotopes (deuterium and tritium). The fuel is ideally ignited and burns for less than a billionth of a second. In these experiments the inertia of the highly dense plasma is intended to hold it together long enough to produce fusion conditions.

In magnetic fusion, various topologies of magnetic fields are used to confine the plasma and prevent it from cooling off through contact with the relatively cold vessel wall. A magnetic field is used to hold a plasma together so that it can be heated to fusion temperatures to produce useful energy. The confinement time in the most advanced geometry used to date, the tokamak, is on the order of seconds, and the density of the plasma is much less than that of the ICF experiments. Magnetic fusion and ICF thus differ from each other by several orders of magnitude in key parameters, yet both are projected to cost several billion dollars and require many years of development.

Magnetized target fusion (MTF) is an intermediate approach to fusion between magnetic fusion and ICF in terms of plasma density and implosion time scales. In MTF, a magnetic field reduces the rate at which heat is lost to the walls of the containment vessel by inhibiting the motion of charged particles. Ideally, the cost, complexity, and development time for MTF offer a significant improvement over the magnetic fusion and ICF schemes. In MTF, the magnetic field does not confine the plasma. In fact, the plasma is confined by the walls of a solid chamber. Once a "magnetized target plasma" is produced, the containment vessel must be imploded. This process performs work on the plasma, adiabatically heating it to ignition conditions. MTF is in some sense a slow ICF concept; the magnetic field reduces the thermal conduction and allows the implosion to proceed in millionths rather than billionths of a second. More efficient and energetic implosion drivers and larger and more manageable targets can thus be used.

Researchers at Los Alamos and the Russian nuclear weapons laboratory VNIIEF, located at Arzamas-16, are examining an MTF plasma-formation scheme in an historically significant program involving experiments at both institutions. This scheme is known by the Russian acronym MAGO. Los Alamos scientists have participated actively in three MAGO experiments to date. In these experiments, researchers did not attempt to implode the containment chamber itself but only to study the formation and characteristics of the target plasma.

In the MAGO experiments, a 20-cm-diam cylindrical copper chamber is filled with a static gas mixture of deuterium and tritium (Fig. 1). The chamber is attached to the end of an explosive pulsed-power generator. During Stage I, the generator produces a current of 2 MA in a few hundred microseconds (Fig. 2). The magnetic field that is created as the current flows through the chamber will reduce heat losses. The yellow arrows in Fig. 1 indicate the flow of current around the center electrode. The current returns on the inner surface of the MAGO chamber. The relatively slow rate at which the current rises ensures that no electrical breakdown in the deuterium-tritium gas mixture occurs during this stage. Through a sophisticated explosive switching system, the chamber is then temporarily disconnected from the generator. The chamber current maintains the insulating magnetic field produced in Stage I while the generator current continues to rise to about 8 MA during Stage II. Additional explosive switching then reconnects the chamber to the generator in Stage III, and the rapid rise in current causes a breakdown of the gas within the chamber, creating a plasma (see Fig. 1).

Calculations and experimental measurements of the dynamic process in Stage III suggest that the breakdown of the gas mixture first occurs in the "nozzle" region (*i.e.*, the silver illuminated region in Fig. 1 surrounding the center electrode). This breakdown produces an ionizing shock wave that creates some plasma in region 2 of the MAGO chamber. According to calculations, this process is followed by a breakdown of the gas mixture in region 1. The subsequent plasma that is formed is magnetically driven around the center electrode, swept into the "nozzle" region, and then accelerated into the shock-wave-produced plasma of region 2. A burst of neutrons is produced via the stagnation of the accelerated plasma in region 2, and a relatively quiescent, warm, dense plasma is then formed. This plasma leans against the walls in region 2 but is also insulated from these walls by the magnetic field produced during Stage I. Ideally, the MAGO chamber geometry creates a magnetized target suitable for imploding and heating to thermonuclear conditions.

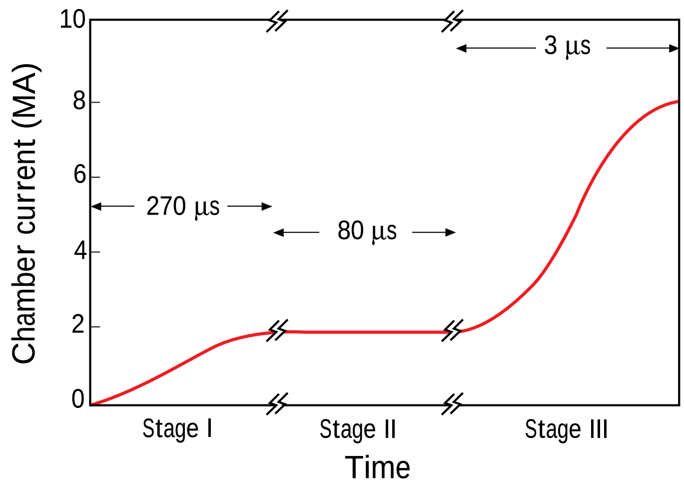

Fig. 2. Current rise as associated with Stages I, II, and III.

Raising the temperature of the plasma in region 2 to thermonuclear values requires a totally separate generator system with tens or hundreds of megajoules of energy. Our colleagues at VNIIEF have developed a novel high-explosive disk generator that is both energetic and modular, and this generator might be used to implode the walls of region 2 on a future MAGO experiment.

The diagnostics for the three MAGO shots performed to date have been focused on understanding the plasma-formation mechanism and on determining the concentration of impurities (*i.e.*, associated with the material from the walls and insulator) that mix with the plasma. Experimentalists have examined the plasma density, the neutron production, and the emitted radiation (both in the visible and x-ray portions of the spectrum) to learn how MAGO works. The ultimate goal of these investigations is to perform a full-scale MTF experiment using the MAGO concept.

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